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AUTHOR(S):

神谷, 徳昭

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# On $(\alpha, \beta, \gamma)$ -structurable algebras and Dynkin diagrams<sup>1</sup> —Beyond Lie algebras to triple systems—

NORIAKI KAMIYA

Center for Mathematical Sciences, University of Aizu, 965-8580 Aizuwakamatsu, Japan

E-mail: kamiya@u-aizu.ac.jp

DANIEL MONDOC

Centre for Mathematical Sciences, Lund University, 22 100 Lund, Sweden

E-mail: Daniel.Mondoc@math.lu.se

**Abstract.** In this paper we introduce the notion of  $(\alpha, \beta, \gamma)$ -structurable algebras, where  $\alpha, \beta, \gamma \in \{-1, 0, 1\}$ , and give examples of such structures.

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*Keywords:* (anti-)structurable algebras, triple systems, Lie algebras, Lie superalgebras

## 1 Introduction

Our start point in a historical setting is the construction of Lie (super)algebras starting from a class of nonassociative algebras. Freudenthal ([18]), Tits ([65]), I.L. Kantor ([43]-[45]) and Koecher ([48]) studied constructions of Lie algebras from nonassociative algebras and triple systems, in particular Jordan algebras. B.N. Allison ([3], [4]) defined structurable algebras which are a class of nonassociative algebras with involution that include Jordan algebras (with trivial involution), associative algebras with involution, and alternative algebras with involution. They are related to generalized Jordan triple systems of 2nd order (or  $(-1, 1)$ -Freudenthal Kantor triple systems) as introduced and studied in [43], [44] and further studied in [5], [7], [42], [51]-[54], [62]. Their importance lies with constructions of 5-graded Lie algebras  $L(\varepsilon, \delta) = \sum_{k=-2}^2 L_k$ ,  $[L_i, L_j] \subseteq L_{i+j}$ , including the three gradings for the cases  $L_{-2} = 0 = L_2$ . Recently, we have studied constructions of Lie (super)algebras from triple systems and anti-structurable algebras ([33], [35], [38]-[41]).

As a continuation of [38], [39] we give here further generalization of structurable algebras. Hence within the general framework of  $(\varepsilon, \delta)$ -Freudenthal Kantor triple systems  $(\varepsilon, \delta = \pm 1)$  and the standard embedding Lie (super)algebra construction ([14], [15], [22]-[24], [30], [35], [49], [50], [61], [67]) we define  $(\alpha, \beta, \gamma)$ -structurable algebras as a class of nonassociative algebras with involution which coincides with the class of structurable algebras for  $(\alpha, \beta, \gamma) = (1, 1, -1)$ . For  $(\alpha, \beta, \gamma) = (1, -1, 1)$  the notion coincides with anti-structurable algebras ([38]) that may similarly shed light on of  $(-1, -1)$ -Freudenthal Kantor triple systems hence, by [14], [15], on the construction of Lie and Jordan superalgebras. While in this paper the

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<sup>1</sup>This is an announcement note and the details will be published elsewhere

definition of  $(\alpha, \beta, \gamma)$ -structurable algebras suppose an underling unital algebra structure we mention the construction of quasi  $\delta$ -structurable algebras ([40]) when no assumption of existence of unit element is made.

Jordan and Lie (super)algebras ([17], [21]) play an important role in mathematics and physics ([11], [19]-[22], [24], [34], [37], [46], [58], [59], [64], [68], [69]) and the construction and characterization of these algebras can be expressed in terms of triple systems ([28], [32], [35], [36], [47], [60]) by the standard embedding method. Specially, we mention the connection between  $N \leq 8$  3-algebras (or triple systems) with  $N$ -supersymmetric 3-dimensional Chern-Simons gauge theories ([2],[8]-[10]) and Lie superalgebra constructions studied in terms of anti-Jordan triple systems and anti-Lie triple systems ([12], [13]).

## 2 Definitions and preamble, structures and examples

### 2.1 $(\varepsilon, \delta)$ -Freudenthal Kantor triple systems, $\delta$ -Lie triple systems, and Lie (super)algebras

In this paper triple systems have finite dimension over a field  $\Phi$  of characteristic  $\neq 2$  or 3.

A vector space  $V$  over a field  $\Phi$  endowed with a trilinear operation  $V \times V \times V \rightarrow V$ ,  $(x, y, z) \mapsto (xyz)$  is said to be a *GJTS of 2nd order* if the following conditions are fulfilled:

$$(ab(xyz)) = ((abx)yz) - (x(bay)z) + (xy(abz)), \quad (2.1)$$

$$K(K(a, b)x, y) - L(y, x)K(a, b) - K(a, b)L(x, y) = 0, \quad (2.2)$$

where  $L(a, b)c := (abc)$  and  $K(a, b)c := (acb) - (bca)$ .

A *Jordan triple system* (for short JTS) satisfies (2.1) and the condition ([19])

$$(abc) = (cba). \quad (2.3)$$

while an *anti-JTS* satisfies (2.1) and the condition ([35])

$$(abc) = -(cba). \quad (2.4)$$

A *generalized Jordan triple system* (for short GJTS) satisfies only the condition (2.1).

We can generalize the concept of GJTS of 2nd order as follows (see [22], [23], [26]-[30], [67] and the earlier references therein).

For  $\varepsilon = \pm 1$  and  $\delta = \pm 1$ , a triple product that satisfies the identities

$$(ab(xyz)) = ((abx)yz) + \varepsilon(x(bay)z) + (xy(abz)), \quad (2.5)$$

$$K(K(a, b)x, y) - L(y, x)K(a, b) + \varepsilon K(a, b)L(x, y) = 0, \quad (2.6)$$

where

$$L(a, b)c := (abc), \quad K(a, b)c := (acb) - \delta(bca), \quad (2.7)$$

is called an  $(\varepsilon, \delta)$ -Freudenthal Kantor triple system (for short  $(\varepsilon, \delta)$ -FKTS).

**Remark.** We note that  $K(b, a) = -\delta K(a, b)$ .

Let  $U$  be a GJTS of 2-nd order  $U$  and let  $V_k, k = 1, 2, 3$ , be subspaces of  $U$ . We denote by  $(V_1, V_2, V_3)$  the subspace of  $U$  spanned by elements  $(x_1, x_2, x_3), x_k \in V_k, k = 1, 2, 3$ . A subspace  $V$  of  $U$  is called an ideal of  $U$  if the following relations hold  $(V, U, U) \subseteq V, (U, V, U) \subseteq V, (U, U, V) \subseteq V$ .  $U$  is called *simple* if  $(\ , \ , \ )$  is not a zero map and  $U$  has no nontrivial ideal. **Remark.** The concept of GJTS of 2nd order coincides with that of  $(-1, 1)$ -FKTS. Thus we can construct the simple Lie algebras by means of the standard embedding method ([14], [22]-[26], [30], [33], [35], [45], [67]).

An  $(\varepsilon, \delta)$ -FKTS  $U$  is called *unitary* if the identity map  $Id$  is contained in  $\kappa := K(U, U)$  i.e., if there exist  $a_i, b_i \in U$ , such that  $\sum_i K(a_i, b_i) = Id$ .

For  $\delta = \pm 1$ , a triple system  $(a, b, c) \mapsto [abc], a, b, c \in V$  is called a  $\delta$ -Lie triple system (for short  $\delta$ -LTS) if the following three identities are fulfilled

$$\begin{aligned} [abc] &= -\delta[bac], \\ [abc] + [bca] + [cab] &= 0, \\ [ab[xyz]] &= [[abx]yz] + [x[aby]z] + [xy[abz]], \end{aligned} \quad (2.8)$$

where  $a, b, x, y, z \in V$ . An 1-LTS is a LTS while a  $-1$ -LTS is an *anti-LTS*, by [23].

**Proposition 2.1** ([23],[30]) *Let  $U(\varepsilon, \delta)$  be an  $(\varepsilon, \delta)$ -FKTS. If  $J$  is an endomorphism of  $U(\varepsilon, \delta)$  such that  $J < xyz > = < JxJyJz >$  and  $J^2 = -\varepsilon\delta Id$ , then  $(U(\varepsilon, \delta), [xyz])$  is a LTS (if  $\delta = 1$ ) or an anti-LTS (if  $\delta = -1$ ) with respect to the product*

$$[xyz] := < xJyz > - \delta < yJxz > + \delta < xJzy > - < yJzx >. \quad (2.9)$$

**Corollary 2.1** *Let  $U(\varepsilon, \delta)$  be an  $(\varepsilon, \delta)$ -FKTS. Then the vector space  $T(\varepsilon, \delta) = U(\varepsilon, \delta) \oplus U(\varepsilon, \delta)$  becomes a LTS (if  $\delta = 1$ ) or an anti-LTS (if  $\delta = -1$ ) with respect to the triple product defined by*

$$\left[ \begin{pmatrix} a \\ b \end{pmatrix} \begin{pmatrix} c \\ d \end{pmatrix} \begin{pmatrix} e \\ f \end{pmatrix} \right] = \begin{pmatrix} L(a, d) - \delta L(c, b) & \delta K(a, c) \\ -\varepsilon K(b, d) & \varepsilon(L(d, a) - \delta L(b, c)) \end{pmatrix} \begin{pmatrix} e \\ f \end{pmatrix} \quad (2.10)$$

Thus we can obtain the standard embedding Lie algebra (if  $\delta = 1$ ) or Lie superalgebra (if  $\delta = -1$ ),  $L(\varepsilon, \delta) = D(T(\varepsilon, \delta), T(\varepsilon, \delta)) \oplus T(\varepsilon, \delta)$ , associated to  $T(\varepsilon, \delta)$  where  $D(T(\varepsilon, \delta), T(\varepsilon, \delta))$  is the set of inner derivations of  $T(\varepsilon, \delta)$ , i.e.

$$Der T := D(T(\varepsilon, \delta), T(\varepsilon, \delta)) := \left\{ \begin{pmatrix} L(a, b) & \delta K(c, d) \\ -\varepsilon K(e, f) & \varepsilon L(b, a) \end{pmatrix} \right\}_{span},$$

$$T(\varepsilon, \delta) := \left\{ \begin{pmatrix} x \\ y \end{pmatrix} \middle| x, y \in U(\varepsilon, \delta) \right\}_{span}.$$

**Remark.** We note that  $L(\varepsilon, \delta) := \sum_{k=-2}^2 L_k$  is the 5-graded Lie (super)algebra, such that  $T(\varepsilon, \delta) = L_{-1} \oplus L_1$  and  $D(T(\varepsilon, \delta), T(\varepsilon, \delta)) = L_{-2} \oplus L_0 \oplus L_2$  with  $[L_i, L_j] \subseteq L_{i+j}$ . This Lie (super)algebra construction is one of the reasons to study nonassociative algebras and triple systems.

## 2.2 $(\alpha, \beta, \gamma)$ -structurable algebras with examples

Let  $(\mathcal{A}, -)$  be a finite dimensional nonassociative unital algebra with involution (involutive anti-automorphism, i.e.  $\bar{\bar{x}} = x, \overline{xy} = \bar{y}\bar{x}, x, y \in \mathcal{A}$ ) over  $\Phi$ . The identity element of  $\mathcal{A}$  is denoted by 1. Since  $\text{char}\Phi \neq 2$ , by [3] we have  $\mathcal{A} = \mathcal{H} \oplus \mathcal{S}$ , where  $\mathcal{H} = \{a \in \mathcal{A} | \bar{a} = a\}$  and  $\mathcal{S} = \{a \in \mathcal{A} | \bar{a} = -a\}$ .

Suppose  $x, y \in \mathcal{A}$  and put  $[x, y] := xy - yx$ . Let the operators  $L_x$  and  $R_x$  be defined by  $L_x(y) := xy, R_x(y) := yx, x, y \in \mathcal{A}$  and for  $\alpha, \beta, \gamma \in \{-1, 0, 1\}$  define

$$V_{x,y}^{\alpha,\beta,\gamma} := \alpha L_{L_x(\bar{y})} + \beta R_x R_{\bar{y}} + \gamma R_y R_{\bar{x}}, \quad (2.11)$$

$$B_{\mathcal{A}}^{\alpha,\beta,\gamma}(x, y, z) := V_{x,y}^{\alpha,\beta,\gamma}(z) = \alpha(x\bar{y})z + \beta(z\bar{y})x + \gamma(z\bar{x})y, x, y, z \in \mathcal{A}. \quad (2.12)$$

We call  $B_{\mathcal{A}}^{\alpha,\beta,\gamma}(x, y, z)$  the  $(\alpha, \beta, \gamma)$ -triple system obtained from the algebra  $(\mathcal{A}, -)$  and write for short

$$V_{x,y} := V_{x,y}^{\alpha,\beta,\gamma}, \quad B_{\mathcal{A}} := (B_{\mathcal{A}}^{\alpha,\beta,\gamma}, \mathcal{A}). \quad (2.13)$$

We call an unital non-associative algebra with involution  $(\mathcal{A}, -)$  an  $(\alpha, \beta, \gamma)$ -structurable algebra if the following identity is fulfilled

$$[V_{u,v}, V_{x,y}] = V_{V_{u,v}(x), y} - V_{x, V_{v,u}(y)}, \quad u, v, x, y \in \mathcal{A}. \quad (2.14)$$

**Remark.** If  $(\alpha, \beta, \gamma) = (1, 1, -1)$  then  $(\mathcal{A}, -)$  coincides with the notion of *structurable algebra* ([3]). Then, by [44], the triple system  $B_{\mathcal{A}}$  is a GJTS and by [16],  $B_{\mathcal{A}}$  is a GJTS of 2nd order, i.e. satisfies the identities (2.5) and (2.6). Further, if  $(\alpha, \beta, \gamma) = (1, -1, 1)$  then  $(\mathcal{A}, -)$  coincides with the notion of *anti-structurable algebra* ([38]). If  $(\mathcal{A}, -)$  is anti-structurable then we call  $B_{\mathcal{A}}$  an *anti-GJTS*.

We give now examples of structurable, anti-structurable and  $(1, 1, 0)$ -structurable algebras over the fields  $\mathbb{C}$  and  $\mathbb{R}$ , respectively and finish with the examples of  $(1, -1, 0)$ -structurable algebras over  $\mathbb{C}$  and  $(0, 1, 0)$ -structurable algebras over an associative algebra with involution. We use the notations of [7], [42]. With regard to Lie algebras and Dynkin diagrams we refer to [63]. In the case of real Lie algebras we omit the corresponding Satake diagrams aiming for a shorter text. We also recall the following definitions.

A GJTS of 2-nd order is called *exceptional (classical)* if its embedding Lie algebra is exceptional (classical) Lie algebra.

Two GJTSs of 2-nd order  $(B, U)$  and  $(B', U')$  are called *weakly isomorphic* if there exists bijective linear maps  $M, N : U \rightarrow U'$  such that  $M(B(x, y, z)) = B'(M(x), N(y), M(z))'$ ,  $x, y, z \in U$ . A linear map  $F : U \rightarrow U'$  is called a *homomorphism* if  $F$  satisfies the identity  $F(B(x, y, z)) = B'(F(x), F(y), F(z))$ , for all  $x, y, z \in U$ . Moreover, if  $F$  is bijective, then  $F$  is called an *isomorphism*. In this case the GJTSs of 2-nd order  $(B, U)$  and  $(B', U')$  are said to be *isomorphic*.

Let  $(B, U)$  be a GJTS of 2-nd order and let the linear endomorphisms  $L_{x,y}, R_{x,y}$  on  $U$  be defined by  $L_{x,y}(z) := B(x, y, z), R_{x,y}(z) := B(z, x, y), x, y, z \in U$ . If  $(B, U)$  be a finite dimensional GJTS of 2-nd order then consider the symmetric bilinear form on  $U$  defined by  $\gamma_B(x, y) := \frac{1}{2} \text{Tr}(2R_{x,y} + 2R_{y,x} - L_{x,y} - L_{y,x})$  ([66], [71]), where  $\text{Tr}(f)$  means the trace of a linear endomorphism  $f$ . We shall call the form  $\gamma_B$  the *canonical (trace) form* for the GJTS of 2-nd order  $(B, U)$ . A finite dimensional GJTS of 2-nd order  $(B, U)$  is called *compact* if its canonical form  $\gamma_B$  is positive definite.

We give first examples of structurable over the field  $\mathbb{C}$  such that the corresponding standard embedding Lie algebra is simple classical 5-graded. By historical reasons ([44]) the corresponding standard embedding Lie algebra is denoted  $\mathfrak{g} = \oplus_{l=-2}^2 \mathfrak{g}_l$ . We also denote

$M_{p,q}(\mathbb{C})$ : the vector space of all  $p \times q$  complex matrices,

$x^\top$ : the transposed matrix of a matrix  $x$ ,

$x^*$ : the transposed conjugate matrix of  $x$ ,

$\tilde{J}_n = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes J_n = \begin{pmatrix} 0 & J_n \\ -J_n & 0 \end{pmatrix}$ , where  $J_n = (a_{i,j})$  is the matrix of order  $n$  such that  $a_{i,j} = \delta_{i,n+1-j}$  and  $\delta_{i,j}$  denotes the Kronecker's delta,

$Alt'_n(\mathbb{C}) = \{x \in M_{n,n}(\mathbb{C}) | x^\top J_n + J_n x = 0\}$ .

By means of these notation, we have the following.

**Proposition 2.2** ([7], [44], [71]) *Let  $(U, \{ \})$  be a classical complex simple GJTS of 2-nd order and  $\mathfrak{g} = \oplus_{l=-2}^2 \mathfrak{g}_l$  be the corresponding standard embedding Lie algebra. Then  $(U, \{ \})$  are classified (up to weak isomorphism) as follows*

$$1. \mathfrak{g} = \mathfrak{sl}(n, \mathbb{C}), \quad \mathfrak{g}_{-1} = U = \begin{pmatrix} M_{p,q}(\mathbb{C}) \\ M_{q,r}(\mathbb{C}) \end{pmatrix}, \quad 1 \leq p \leq \left\lfloor \frac{n}{2} \right\rfloor, \quad p \leq r, \quad p + q + r = n,$$

$$\{XYZ\} = \left\{ \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix} \begin{pmatrix} Z_1 \\ Z_2 \end{pmatrix} \right\} = \left\{ \begin{pmatrix} X_1 Y_1^* Z_1 + Z_1 Y_1^* X_1 - Z_1 X_2 Y_2^* \\ X_2 Y_2^* Z_2 + Z_2 Y_2^* X_2 - Y_1^* X_1 Z_2 \end{pmatrix} \right\},$$

$$2. \mathfrak{g} = \mathfrak{so}(m, \mathbb{C}), \quad \mathfrak{g}_{-1} = U = M_{k,m-2k}(\mathbb{C}), \quad \begin{cases} \text{a. } 2 \leq k \leq n, \quad m = 2n + 1, \\ \text{b. } 2 \leq k < n, \quad m = 2n \quad (n \geq 4), \end{cases}$$

$$\{XYZ\} = XY^*Z + ZY^*X - ZJ_{m-2k}X^\top \bar{Y}J_{m-2k},$$

$$3. \mathfrak{g} = \mathfrak{so}(2n, \mathbb{C}), \quad \mathfrak{g}_{-1} = U = \begin{pmatrix} M_{1,n-1}(\mathbb{C}) \\ Alt'_{n-1}(\mathbb{C}) \end{pmatrix}, \quad n \geq 5,$$

$$\left\{ \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix} \begin{pmatrix} Z_1 \\ Z_2 \end{pmatrix} \right\} = \left\{ \begin{pmatrix} X_1 Y_1^* Z_1 + Z_1 Y_1^* X_1 - Z_1 X_2 Y_2^* \\ X_2 Y_2^* Z_2 + Z_2 Y_2^* X_2 - Y_1^* X_1 Z_2 - Z_2 J_{n-1} X_1^\top \bar{Y}_1 J_{n-1} \end{pmatrix} \right\},$$

$$4. \mathfrak{g} = \mathfrak{sp}(n, \mathbb{C}), \quad \mathfrak{g}_{-1} = U = M_{k,2n-2k}(\mathbb{C}), \quad 1 \leq k \leq n-1 \quad (n \geq 3),$$

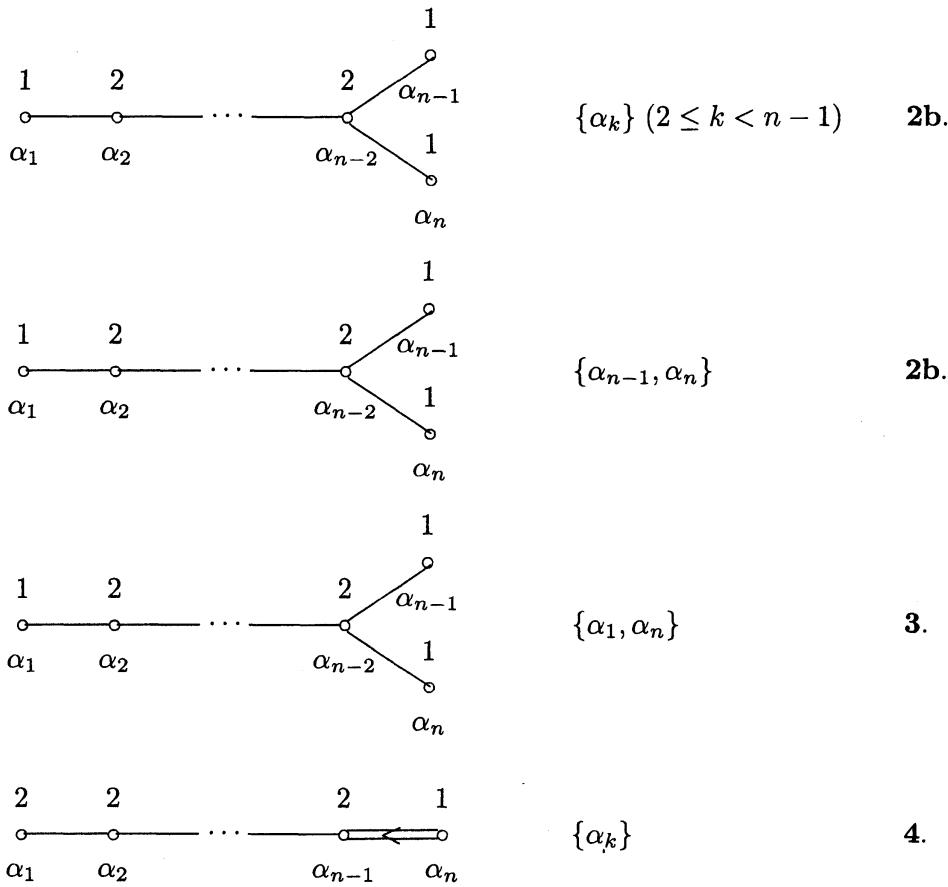
$$\{XYZ\} = XY^*Z + ZY^*X + Z\tilde{J}_{n-k}X^\top \bar{Y}\tilde{J}_{n-k}.$$

Moreover the corresponding Dynkin diagrams with the grading roots are given in Table 1.

Table 1. Dynkin diagrams with coefficients of highest root and grading roots

$$\begin{array}{c} 1 \quad 1 \quad \quad \quad 1 \quad 1 \\ \circ \text{---} \circ \text{---} \cdots \text{---} \circ \text{---} \circ \\ \alpha_1 \quad \alpha_2 \quad \quad \quad \alpha_{n-2} \quad \alpha_{n-1} \end{array} \quad \{\alpha_p, \alpha_{p+q}\} \quad 1.$$

$$\begin{array}{c} 1 \quad 2 \quad \quad \quad 2 \quad 2 \\ \circ \text{---} \circ \text{---} \cdots \text{---} \circ \text{---} \circ \\ \alpha_1 \quad \alpha_2 \quad \quad \quad \alpha_{n-1} \quad \alpha_n \end{array} \quad \{\alpha_k\} \quad 2a.$$



Following [70], we can obtain the structurable algebras from the GJTS of 2nd order with a left unital element  $e$  such that  $eex = x$  for all  $x$ .

Thus we have the following theorem (the details will be discussed in future).

**Theorem 2.1** *Under the assumption as in above, we can obtain the structurable algebras as follows:*

1) case  $p = q = r$ ,  $e = (Id_p, Id_p)^T$ ,  $\{\alpha_p, \alpha_{2p}\}$ ,  $Der T = A_{p-1} \oplus A_{2p-1} \oplus \mathbb{C}$ ,

2) case  $k = m - 2k$ ,  $e = Id_k$ ,  $\{\alpha_k\}$

$Der T = D_k \oplus B_{n-k}$  if  $m = 2n + 1$ ,

$Der T = D_k \oplus D_{n-k}$  if  $m = 2n$ ,

3) case no example

4) case  $k = 2n - 2k$ .  $e = Id_k$ ,  $\{\alpha_k\}$

$Der T = C_k \oplus C_{n-k}$ .

Proof.

Indeed, for example (2) (resp. (4)), the structurable algebra obtained from GJTS of 2nd order with  $e$  is given by

$$\{xyz\} = (x \cdot \bar{y}) \cdot z + (z \cdot \bar{y}) \cdot x - (z \cdot \bar{x}) \cdot y,$$

where this involution is defined by  $\bar{x} = J_k x^T J_k$ , (resp.  $\bar{x} = -\tilde{J}_{n-k} x^T \tilde{J}_{n-k}$ ) and we denote the product of structurable by  $x \cdot y$  (i.e.,  $x \cdot y = xy$  by usual matrix product).

Hence we have

$$\overline{x \cdot y} = \bar{y} \cdot \bar{x}, \quad \bar{\bar{x}} = x.$$

Also other case has same proofs.

**Remark.** For examples of structurable over the field  $\mathbb{C}$  such that the corresponding standard embedding Lie algebra is simple exceptional 5-graded we refer to [43], [44], [71] and we can get their examples of structurable by means of choose a left unit element  $e$  in the GJTS of 2nd order as same methods to Theorem 2.1.

For the JTS, we can obtain the  $(1, 1, 0)$  structurable fom JTS. That is, we note that examples of structurable algebras induced from Jordan triple systems  $U$  w.r.t.

$$\{xyz\} = xy^*z + zy^*x$$

can be obtained same as in Theorem 2.1 by means of the element  $e$  such that  $L(e, e)x = x$  for all  $x \in U$ .

We give now examples of anti-structurable algebras or  $(1, -1, 1)$ -structurable algebras over  $\mathbb{C}$ . Let  $U = M_{m,n}(\mathbb{C})$  with the multiplication  $\{xyz\} = x\bar{y}^\top z - z\bar{y}^\top x + z\bar{x}^\top y$ . Then  $U$  is a  $(-1, -1)$ -FKTS and  $U = M_{n,n}(\mathbb{C})$  is an anti-structurable algebra, by [41]. Then by [38], the following construction of Lie superalgebras is obtained by the standard embedding method. If  $U = M_{2n,m}(\mathbb{C})$  with the product above, then the corresponding standard embedding Lie superalgebra is  $osp(2n|2m) = D(n, m)$  (as defined by [17]), hence the standard embedding Lie superalgebra of the anti-structurable algebra  $M_{2n,2n}(\mathbb{C})$  is  $osp(2n|4n)$ . Similarly, if  $U = M_{2n+1,m}(\mathbb{C})$  with the product above, then the corresponding standard embedding Lie superalgebra is  $osp(2n+1|2m) = B(n, m)$  (as defined by [17]), hence the standard embedding Lie superalgebra of the anti-structurable algebra  $M_{2n+1,2n+1}(\mathbb{C})$  is  $osp(2n+1|4n+2)$ .

Finally, the last two examples refers to  $(1, -1, 0)$  and  $(0, 1, 0)$ -structurable algebras. We start first with examples of  $(1, -1, 0)$ -structurable algebras over  $\mathbb{C}$ .

Let  $U = M_{n,n}(\mathbb{C})$  with multiplication  $\{xyz\} = xy^\top z - zy^\top x$ ,  $x, y, z \in U$  and set  $\{XYZ\} = \begin{pmatrix} 0 & -xy'z + zy'x \\ x'yz' - z'yx' & 0 \end{pmatrix}$ , such that  $x, y, z$  are symmetric and  $x', y', z'$  are skew-symmetric.

Let  $V$  be the vector space  $V = \left\{ X = \begin{pmatrix} 0 & x \\ x' & 0 \end{pmatrix} \in M_{2n,2n}(\mathbb{C}) \mid x = x^\top, x' = -x'^\top \right\}$ . Then, by [35], the product  $\{XYZ\}$  is an anti-JTS. By [35], we introduce in  $V$  a new product  $(XYZ) = \{XPYZ\} = \begin{pmatrix} 0 & xy'z - zy'x \\ x'yz' - z'yx' & 0 \end{pmatrix} \in V$ , where  $P = \begin{pmatrix} 0 & -Id \\ Id & 0 \end{pmatrix}$ . Then  $V$  with the product  $(XYZ)$  above is an anti-JTS and the standard embedding Lie superalgebra is  $P(n-1)$  as defined in [17] with a 3-graded structure ([35]).

Let now  $U$  be a  $(0, 1, 0)$ -structurable algebras with product  $(xyz) = (z\bar{y})x$  and involution  $-$ . If  $U = A$  in an associative algebra thus  $(xyz) = z\bar{y}x$  it is a straightforward calculation to show that  $(xyz)$  is a GJTS which is not of second order and not a JTS or anti-JTS.

**Remark.** For the  $(-1, -1)$ -FKTS  $U := M_{k,k}(\Phi)$  with product  $(xyz) = xy^\top z - zy^\top x + zx^\top y$  ([38]), since  $K(x, y) = L(y, x) + L(x, y)$  we can easily show that there exists an almost complex structure on the associated anti-LTS  $T(-1)$ . Moreover, by [38], the standard embedding Lie superalgebra  $L(U)$  corresponding to the  $(-1, -1)$ -FKTS above is  $osp(k|2k)$ .



if  $k = 2m$  or  $k = 2m + 1$ , respectively, but by [33], for a structurable algebra with product  $(xyz) = xy^\top z + zy^\top x - zx^\top y$  does not exist an associated almost complex structure.

In end of this note, for an application to M-theory of physics, following [72], we note examples of hermitian  $(-1, -1)$  Freudenthal-Kantor triple systems as follows.

$$a) \{xyz\} = x\bar{y}^T z - z\bar{y}^T x,$$

$$b) \{xyz\} = x\bar{y}^T z - z\bar{y}^T x + zx^T \bar{y},$$

where for all  $x, y, z \in M_{m,n}(\mathbb{C})$ .

These details will be discussed in future paper with Dr.M.Sato.

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